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⑳ Applicant: The Board of Trustees of the  
University of Illinois  
266 Administration Building 506 South  
Wright Street  
Urbana Illinois 61801(US)

㉑ Inventor: Weber, Larry F.  
905 South Lynn  
Champaign, IL 61820(US)  
Inventor: Warren, Kevin W.  
723 South Lynn  
Champaign, IL 61820(US)  
Inventor: Wood, Mark B.  
680 West, 500 South  
Woods Cross Utah 84087(US)

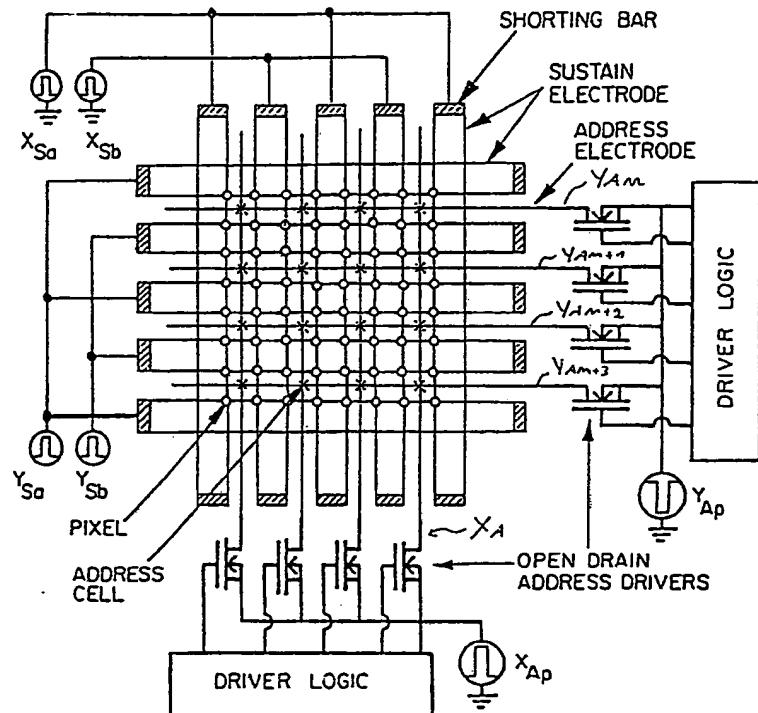
㉒ Representative: Bohnenberger, Johannes, Dr.  
et al  
Meissner, Bolte & Partner  
Widenmayerstrasse 48 Postfach 86 06 24  
D-8000 München 86(DE)

㉓ Method for controlling cells and pixels of plasma panels, plasma display panels,  
electroluminescent panels, lcd's or that like and a circuit for carrying out the method.

㉔ An improved address driver circuit for plasma panels, particularly useful with an independent sustain and address plasma panel. Address pulse generators for one panel address axis are coupled to MOSFET driver devices and provide pulses of a first polarity; and address pulse generators for the other panel address axis are coupled to similar MOSFET driver devices and provide double pulses of a second polarity. With N-channel open-drain MOSFET drivers on both panel address axes, they only need to be designed to pull low. An improved power efficient sustain driver for plasma panels including an inductor through which the panel capacitance is charged and discharged, and switch means switched when the inductor current is zero, which permits recovery of the energy otherwise lost in driving the panel capacitance. An independent sustain and address plasma panel with such energy efficient address drivers and sustain drivers. The energy efficient sustain driver can be used with plasma display panels, electroluminescent panels and with liquid crystal panels having inherent panel capacitance. An independent sustain and address panel with N-channel MOSFET drivers on one address axis and P-channel MOSFET drivers on the other address axis, with an address pulse generator providing pulses of a first polarity to the N-channel MOSFETs, and another address pulse generator providing pulses of a second polarity to the P-channel MOSFETS.

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FIG. 2



**METHOD FOR CONTROLLING CELLS AND PIXELS OF PLASMA PANELS, PLASMA DISPLAY PANELS,  
ELECTROLUMINESCENT PANELS, LCD's OR THAT LIKE AND A CIRCUIT FOR CARRYING OUT THE  
METHOD**

This invention relates to a method for controlling cells and pixels of plasma panels, plasma display panels, electroluminescent panels, LCD's or that like and a circuit for carrying out the method.

**5 BACKGROUND OF THE INVENTION**

Plasma display panels, or gas discharge panels, are well known in the art and, in general, comprise a structure including a pair of substrates respectively supporting thereon column and row electrodes each coated with a dielectric layer such as a glass material and disposed in parallel spaced relation to define a gap therebetween in which an ionized gas is sealed. Moreover, the substrates are arranged such that the electrodes are disposed in orthogonal relation to one another thereby defining points of intersection which in turn define discharge cells at which selective discharges may be established to provide a desired storage or display function. It is also known to operate such panels with AC voltages and particularly to provide a write voltage which exceeds the firing voltage at a given discharge point, as defined by a selected column and row electrode, thereby to produce a discharge at a selected cell. The discharge at the selected cell can be continuously "sustained" by applying an alternating sustain voltage (which, by itself is insufficient to initiate a discharge). This technique relies upon the wall charges which are generated on the dielectric layers of the substrates which, in conjunction with the sustain voltage, operate to maintain discharges.

Details of the structure and operation of such gas discharge panels or plasma displays are set forth in 20 U.S. Patent No. 3,559,190 issued January 26, 1971 to Donald L. Bitzer, et al.

In the past two decades, AC plasma displays have found widespread use due to their excellent optical qualities and flat panel characteristics. These qualities have made plasma displays a leader in the flat-panel display market. However, plasma panels have gained only a small portion of their potential market because of competition from lower costs CRT products.

25 The expense of the display electronics, not the display itself, is the most significant cost factor in plasma displays. Because of the matrix addressing schemes used, a separate voltage driver is required for each display electrode. Therefore, a typical 512×512 pixel display requires a total of 1024 electronic drivers and connections which add considerable bulk and cost to the final product.

In a co-pending U.S. Patent Application Serial Number 787,541 filed October 15, 1985, and assigned to 30 the same assignee as herein, there is described an Independent Sustain and Address (ISA) plasma panel. Also, see the publication L.F. Weber and R.C. Younce, "Independent Sustain And Address Technique For The AC Plasma Display", 1986 Society For Information Display International Symposium Conference Record, pp. 220-223, San Diego, May, 1986. The ISA plasma panel technique includes the addition of an independent address electrode between the sustain electrodes. These address electrodes are then connected to the address drivers. The sustain electrodes can be bused together and connected directly to the sustainers.

35 The ISA plasma panel offers two significant advantages. First, since the address electrodes do not have to deliver the large sustain current to the discharging pixels, the address drivers have low current requirements. This allows lower cost drivers to be used. The second advantage is that only half the number of address drivers are needed since one address electrode can serve the sustain electrode on either side.

40 Despite the significant advantages afforded by the ISA panel, it is still desired to reduce as much as possible the manufacturing cost of such panels. However, while the ISA panel has enabled a reduction of the address drivers of a typical 512×512 pixel display from 1024 electronic address drivers to only 512 drivers, this is still a significant number of required electronic components. In fact, the plasma panel cost is 45 dominated by the cost of the associated required electronic circuits such as the addressing driver circuits and sustain driver circuits. In addition, it is desired to reduce the amount of energy normally lost in charging and discharging the capacitance of the plasma panel.

46 It is therefore the object of the invention to reduce the cost and operational cost of plasma panels, plasma display panels, electroluminescent panels, LCD's or that like by reducing the cost/operational cost 50 of the associated electronics.

SUMMARY OF THE INVENTION

The general concept of the present invention is based on the fact that plasma panels as described above comprise a panel capacitance which needs to be charged and discharged for storing and erasing information and for sustaining stored information.

In accordance with one aspect of the present invention, an improved address driver circuit is provided e.g. for the ISA plasma panel. The new driver circuit utilizes open-drain (N-channel or P-channel) MOSFET output structure which can be made at a lower cost compared to the normally used totem-pole drivers. A unique feature of the present invention resides in a technique used to apply the proper positive and negative pulses to the ISA plasma display panel by using identical, low cost N-channel open-drain MOSFET devices. Thus, in contrast with prior plasma panel address driver circuits that must be able to pull high (i.e., drive the plasma panel with a positive pulse) and pull low (i.e., drive the plasma panel with a negative pulse) the unique feature of the present invention enables the N-channel open-drain MOSFET devices only to be designed to pull low.

In accordance with another aspect of the present invention, a power efficient sustainer circuit has been developed for use with flat panels having substantial inherent panel capacitance due to the panel electrodes, such as plasma display panels, electroluminescent panels, liquid crystal displays, etc. The new sustain driver circuit uses inductors in charging and discharging the panel capacitance so as to recover 90% of the energy normally lost in driving the panel capacitance. Accordingly, a plasma panel incorporating a power efficient sustain driver circuit according to the present invention can operate with only 10% of the energy normally required with prior art plasma panel sustaining circuits.

BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1a, 1b, 1c are schematic representations of switch devices useful in explaining an address circuit driver;

Figure 2 is a plan view of a plasma panel with open-drain address drivers and sustain drivers in accordance with one aspect of the invention;

Figure 3 are waveform diagrams useful in understanding the operation of Figure 2;

Figure 4 are waveform diagrams showing an expanded view of the section of Figure 3 labeled 4-4;

Figure 5 is a schematic circuit diagram showing an ideal model of a new sustain driver according to the invention;

Figure 6 are waveform diagrams useful in understanding the operation of Figure 5;

Figure 7 is a schematic circuit diagram showing a practical circuit model of a new sustain driver according to the invention;

Figure 8 are waveform diagrams useful in understanding the operation of Figures 7 and 9;

Figure 9 and 9a are schematic circuit diagrams showing a constructed embodiment of a new sustain driver according to the invention;

Figure 10 is a schematic circuit diagram of a new sustain driver in an integrated circuit design;

Figure 11 is a schematic circuit diagram of an XAP address pulse driver incorporating energy recovery techniques according to the invention;

Figure 12 are waveform diagrams useful in understanding the operation of Figure 11;

Figure 13 is a schematic circuit diagram of YAP address pulse driver incorporating energy recovery techniques according to the invention; and

Figure 14 are waveform diagrams useful in understanding the operation of Figure 13.

DETAILED DESCRIPTION OF THE DRAWINGS

The present invention will be described in connection with an ISA plasma panel to which has been incorporated a new and improved address driver circuit in accordance with one aspect of this invention, and a new power efficient sustain driver circuit in accordance with another aspect of the present invention. For convenience of description, the first aspect of this invention, i.e., the new and improved address driver circuit will be described followed by the description of the power efficient sustain driver circuit.

### ISA Driver Circuits For Plasma Panels

A major advance of this invention is the simplification of the address circuit drivers. These drivers only need to be designed to pull low. This contrasts with the normal plasma panel circuits that must be able to pull high and pull low. The pull low type driver can be fabricated at considerably lower cost. Figure 1 shows the basic type of address circuit driver that can be used in this invention. Figure 1a shows a simple switch in parallel with a diode. The switch is used to apply selective address pulses to the plasma panel depending on the state (open or closed) of the switch. With today's solid state switching technology, this switch usually takes two forms: the MOS Field Effect Transistor (MOSFET), shown in Figure 1b and the 10 Bipolar transistor shown in Figure 1c. Usually there is an inherent parallel diode associated with these transistors so that the diode in parallel with the switch in Figure 1a should be understood as being included in the circuit model. The examples presented here are for N-channel MOSFETs and npn Bipolar transistors because these are usually the best devices for integration. However, devices of the opposite polarity could be used with the appropriate adjustment in the waveforms and circuits.

15 Figure 2 shows a circuit diagram for applying the concepts of this invention to drive the address electrodes in an ISA plasma panel i.e., a plasma display panel having independent sustain and address electrodes as previously described.

This example uses the N-channel MOSFET devices shown in Figure 1b, but of course other suitable switches could be used. The basic concept is to connect the drain electrode of each MOSFET to each 20 address electrode of the ISA plasma panel and to then connect all of the sources of the MOSFETs on a given display axis to a common bus. When such MOSFET transistors are integrated, it is very easy to fabricate arrays of these transistors when they have all of the sources connected to a common bus. This arrangement is commonly referred to as the open drain configuration. Note that both the X axis and the Y axis address electrodes in Figure 2 use N-channel MOSFETs in the open drain configuration. This has the 25 advantage that the same electrical parts can be used for both the X and the Y axis. This allows lowering of circuit costs because normally two distinct parts must be designed, fabricated and stocked. In addition, a single part will be made at twice the volume of that of the systems that require two parts and therefore the higher volume of the single part will result in lower costs. Two parts are normally required because the X and Y axes require different polarity address pulses. In the example shown here, the X axis requires a 30 positive pulse and the Y axis requires negative pulses. A novel feature of this invention is the technique used to apply the proper positive and negative pulses to the ISA plasma display panel address electrodes by using identical low cost N-channel open drain MOSFET devices.

Figure 3 shows the waveforms used to drive the ISA panel. This shows a portion of the video scan of the panel for addressing the eight rows of pixels shown in Figure 2 in a top to bottom sequence. Other 35 scanning techniques may be used rather than the video scan example illustrated here. Each row of pixels requires two of the 20 microseconds addressing cycles. The top four waveforms show the signals applied by the four sustainers. The phasing of these waveforms selects which of the four pixels surrounding each address cell in Figure 2 can be addressed during a given addressing cycle. The fundamental periodicity of this phasing is every eight addressing cycles because of the sustain electrode connection technique used 40 in Figure 2.

Below the sustain waveforms are the signals associated with the address electrodes. The waveforms labeled XAP and YAP are supplied from address pulse generators that are connected to the common bus of the address driver transistors as shown in Figure 2. These address pulsers generate the special waveforms needed for the address drivers to apply the proper signals to the address electrodes. The XA waveform 45 shows the selective erase signals on the X address electrodes. A high XA level will erase a selected pixel and a low level leaves the pixel on. The YA waveforms for four adjacent Y address electrodes are shown at the bottom of Figure 3.

### 50 Y Axis Operation

We will now investigate the details of how the Figure 2 circuit operates. The Y axis will be examined first since its operation is the simplest. The linear array of open drain transistors have all of their source electrodes connected to a common bus. This bus is connected to a pulse generator called the Y address 55 pulser and labeled YAP. The purpose of this generator is to supply the energy for the address pulses and to determine the shape of the waveforms applied to the selected Y address electrodes. Notice that, as shown in Figure 3, this generator supplies double amplitude negative pulses. For instance, during the address period, a negative pulse needs to be applied to the selected Y address electrodes. During this

period, a negative pulse is generated by YAP and this pulse is applied to the source electrode of all of the Y address transistors. Any transistors that are off do not conduct and their associated plasma panel address electrodes remain at virtually the same potential as they were before the generation of the negative pulse. Any transistors that are turned on will conduct and their associated plasma panel address electrodes will be

5 pulsed negative to cause an address operation in the plasma panel. Any number of Y address electrodes could be selectively pulsed negative with this technique, however, in video mode, the Y axis address electrodes are usually pulsed one at a time in a sequential manner that causes the image to be scanned.

Since the address electrodes of an ISA plasma panel can be reasonably modeled as a simple capacitance, the current through the transistors flows predominantly during the transitions of the YAP

10 generator. During the negative transition of the YAP generator the conduction current must flow predominantly through the transistor. However, during the positive going transition of the negative address pulse (as it returns to the initial level before the application of the negative pulse), the current can flow through both the MOSFET transistor and also through the body diode that is associated with the transistor. This body diode will of course conduct whether the transistor is in the on or off states. This will allow all of the Y address electrodes to be pulled to the same high level when the YAP generator is at its high level.

### X Axis Operation

20 We will now discuss the operation of the X axis circuits shown in Figure 2. This circuit differs from that of the Y axis because the X axis must be capable of applying a positive pulse as opposed to the negative pulse of the Y axis. Note that just like for the Y axis, the array of N-channel open drain MOSFET transistors has all source electrodes connected to a common bus and this bus is connected to the X address pulse generator labeled as XAP. This XAP generator operates quite differently from the YAP generator because of 25 the opposite polarity of the output pulse. The shape of the XAP waveform is two short pulses (see Figure 3 and the expanded view of Figure 4) used to generate a single longer pulse on the plasma panel address electrodes. The first XAP pulse corresponds to the leading edge of the address electrode pulse and the second XAP pulse corresponds to the trailing edge of the address electrode pulse.

Now we examine the first XAP pulse. It is assumed that all of the address electrodes are initially at the 30 same potential as the XAP generator just before the application of the first pulse. As the XAP generator rises, current flows through all of the body diodes of the MOSFET transistors. This pulls up all of the X address electrodes to a level that is just one diode drop lower than the XAP generator. This action continues until the XAP generator reaches its first peak. Note that all X address electrodes are pulsed positive at this time regardless of whether they are selected or not.

35 The selection operation does not occur until the falling edge of the first XAP pulse. During this time, if a positive pulse is to remain on any selected X address electrodes, then the associated MOSFET transistor is turned off. The transistors that are left on will pull their address electrodes down as the first pulse of the XAP generator falls. This action continues until the XAP generator stops falling at the end of the first pulse. At this time, all of the selected address electrodes are at a high voltage level and the unselected address 40 electrodes are at a low level. This situation can continue for a long period until the second XAP pulse. The selected address electrodes are held high by the capacitance of the plasma panel address electrodes to the sustain electrodes. The unselected address electrodes are held at the low voltage of the XAP generator by the MOSFET transistors that are turned on.

The selection pulse can be terminated by turning all of the transistors on while the XAP generator is at 45 the low level. This works but with some undesirable characteristics. First of all, when the selected transistors are turned on, they quickly discharge the voltage of the address electrode. The discharge rate is frequently so fast that a large amount of displacement current flows through the transistors and the plasma panel capacitance. This displacement current can cause a number of problems. First, this current frequently grows and decays at a very fast rate so that large amounts of electrical noise is generated. This noise tends 50 to create problems for other circuits in the system and can easily mis-trigger many of the logic gates that are used to control the operations of the plasma panel. A second problem of this large current is the large energy dissipation that occurs in the transistor to discharge the capacitance. This energy dissipation can be enough to burn out the transistors in some cases. It also makes the transistors hot and requires special heat sinking requirements. In addition, the energy lost in heating these transistors cannot be recovered and it 55 increases the power requirements of the power supply and the power consumption of the plasma display system.

All of these problems can be significantly reduced with the following switching technique. Shortly before the X address pulse needs to fall, the XAP generator begins the rise of its second pulse. Recall that the first XAP pulse was used to initiate the address pulse. During the rise of the second pulse, current flows through the body diodes of the MOSFETs associated with the unselected X address electrodes. If the MOSFETs of the unselected transistors are still on, there will also be some conduction through these MOSFETs. This current charges up the unselected address electrodes and causes their voltage to rise. This charging continues until the second X pulse reaches its peak. At this peak, all of the X axis MOSFETs should be turned on. As the second XAP pulse begins to fall, a current flows through all of the X MOSFETs which discharges all of the address electrodes. This action continues until the second X pulse completes its fall to its lowest level. At this point, all of the address electrodes should be at this low XAP voltage. This is the final stage of the addressing operation and all of the X address electrodes will be held at this low voltage level until the next addressing operation.

The write before erase addressing proceeds with the following sequence. Figure 3 shows that a write pulse is first applied to the YAn + 1 electrode which turns on all of the pixels in the two rows on either side of YAn + 1. After the completion of this write pulse, four erase pulses are used to selectively erase the pixels in the two rows on either side of YAn. The image is introduced in the panel through a selective erase by controlling the voltage of the XA address electrodes during the erase operation. The sequence continues by writing the two rows on either side of YAn + 2 and then selectively erasing the two rows next to YAn + 1. This staggering of the write and erase operation improves panel voltage margins by allowing the written cells to stabilize for at least four cycles before the selective erase operation occurs. Note that the addition of the write operation to the addressing sequence does not require any additional time beyond that already needed for the sustain and selective erase operations. This allows higher update rates.

A key factor that allows the use of low-cost open-drain address drivers is the design of the address pulser waveforms. Figure 3 shows that the YA address electrodes require selectively applied negative pulses and the XA address electrodes require selectively applied positive pulses. The design of the X and Y address pulser waveforms allows these two polarities with the same N-channel IC design.

In summary of the YA operation first, note that the YAP signal applied to the sources of all of the Y address transistors closely follows the selected YA address electrodes signals. At a given time a selected YA electrode transistor is turned on and all of the other YA transistors are kept off. Thus the negative pulse generated by YAP is transferred to the selected YA address electrode.

A summary of the operation of the XA address electrodes is more complicated. This is shown in the Figure 4 expanded view of the Figure 3 waveforms. Note that the XAP waveform shows two short pulses for each XA erase pulse. These pulses define the leading and trailing edges of the XA erase pulse. They have a sine wave shape since in a constructed embodiment of the invention they are generated with an energy recovery circuit similar to the sustain drive circuit described hereinafter. The rise of the first XAP pulse pulls all of the XA address electrodes high through the body diode and conduction channel of the MOSFET address drivers. At the peak of the first XAP pulse the selected MOSFETs are turned off if the selected pixel is to be erased. The MOSFETs that are left conducting will pull their XA address electrodes low as the first XAP pulse falls low. The selected MOSFETs that are not conducting will remain high by means of the capacitance of the address electrode to the sustain electrodes. This high level on the address electrode causes erasure of the pixel.

The rise of the second XAP pulse pulls all of the non-selected XA address electrodes to the same high level as the selected XA address electrodes. At the peak of the second XAP pulse, all of the X axis address drivers are turned on so that the fall of the second XAP pulse will pull all of the address electrodes to the initial low level.

The above XA address technique successfully places positive pulses on the selected XA address electrodes, however, it also places two short positive pulses on the non-selected XA address electrodes that correspond to the pulse of XAP. To prevent these two short pulses from causing mis-addressing of the non-selected pixels, the YAP pulse is properly phased as shown in Figure 4. The YAP pulse falls after the fall of the first XAP pulse and YAP rises before the rise of the second XAP pulse. This prevents the non-selected XA pulses from adding to the selected YA pulse to cause a mis-addressing discharge.

One concern is that when the column drivers are in a high impedance state, the pulses applied to a neighboring electrode in the low impedance state will capacitively couple to the high impedance electrode and cause it to receive the wrong voltage amplitude. This is not a significant problem for two reasons. First, note that in Figure 2, the address electrodes are shielded from each other by the sustain electrodes. This makes the variations in pulse amplitude, due to address line-to-line coupling, less than 10% of the address pulse amplitude as shown in Figure 4. The second point is that this 10% variation is not a significant problem because of the excellent address margins of the ISA design.

Standard voltage pulse generators can be used as the XAP and YAP address pulse generators supplying the corresponding waveforms of Figure 3. Alternatively, the energy recovery technique described hereinafter with respect to the power efficient sustain driver circuit can be used for the XAP and YAP address pulse generators.

5

### Power Efficient Sustain Drive Circuit

The plasma panel requires a high voltage driver circuit called a sustainer, or sustain driver circuit, which drives all the pixels and dissipates considerable power. As an example, four sustainer drivers XSA, XSB, YSA, YSB are shown in Figure 2 with the ISA panel.

The following describes a new high-efficiency sustainer that eliminates most of the power dissipation resulting from driving the plasma panel with a conventional sustainer. With this new sustainer, considerable savings can be realized in the overall cost of the plasma panel. The new sustainer can be applied to standard plasma panels, or the new ISA plasma panel, as well as to other types of display panels requiring a high voltage driver, such as electroluminescent or liquid crystal panels having inherent panel capacitance.

When the plasma panel is used as a display, frequent discharges are made to occur by alternatively charging each side of the panel to a critical voltage, which causes repeated gas discharges to occur. This alternating voltage is called the sustain voltage. If a pixel has been driven "ON" by an address driver, the sustainer will maintain the "ON" state of that pixel by repeatedly discharging that pixel cell. If a pixel has been driven "OFF" by an address driver, the voltage across the cell is never high enough to cause a discharge, and the cell remains "OFF".

The sustainer must drive all of the pixels at once; consequently, the capacitance as seen by the sustainer is typically very large. In a 512 $\times$ 512 panel, the total capacitance of all the pixel cells in the panel, Cp, could be as much as 5 nF.

Conventional sustainers drive the panel directly, and thus  $1/2CpV_s^2$  is dissipated in the sustainer when the panel is subsequently discharged to ground. In a complete sustain cycle, each side of the panel is charged to  $V_s$  and subsequently discharged to ground. Therefore, a total of  $2CpV_s^2$  is dissipated in a complete sustain cycle. The power dissipation in the sustainer is then  $2CpV_s^2 f$ , where f is the sustain cycle frequency. For  $Cp = 5nF$ ,  $V_s = 100V$ , and  $f = 50$  kHz, the power dissipation in the sustainer, resulting from driving the capacitance of the panel, is 5 W.

If an inductor is placed in series with the panel, then Cp can be charged and discharged through the inductor. Ideally, this would result in zero power dissipation since the inductor would store all of the energy otherwise lost in the output resistance of the sustainer and transfer it to or from Cp. However, switching devices are needed to control the flow of energy to and from the inductor, as Cp is charged and discharged. The "ON" resistance, output capacitance, and switching transition time are characteristics of these switching devices that can result in significant energy loss. The amount of energy that is actually lost due to these characteristics, and hence the efficiency, is determined largely by how well the circuit is designed to minimize these losses.

In addition to charging and discharging Cp, the sustainer must also supply the large gas discharge current for the plasma panel. This current, I, is proportional to the number of pixels that are "ON". The resulting instantaneous power dissipation is  $I^2R$ , where R is the output resistance of the sustainer. Thus, the power dissipation due to the discharge current is proportional to  $I^2$ , or the square of the number of pixels that are "ON".

There are two ways to minimize this dissipation. One is to minimize the output resistance of the sustainer by using very low resistance output drivers, and the other is to minimize the number of pixels that are "ON" at any time.

This invention provides a new sustainer circuit that will recover the energy otherwise lost in charging and discharging the panel capacitance, Cp. The efficiency with which the sustainer recovers this energy is here defined the "recovery" efficiency. When Cp is charged to  $V_s$  and then discharged to zero, the energy that flows into and out of Cp is  $CpV_s^2$ ; therefore, the recovery efficiency is defined by

$$\begin{aligned} \text{Eff} &= 100 \times (CpV_s^2 - E_{\text{lost}}) / CpV_s^2 \\ &= 100 \times (1 - (E_{\text{lost}} / CpV_s^2)) \text{ percent} \end{aligned}$$

55

where  $E_{\text{lost}}$  is the energy lost in charging and discharging Cp.

Notice that the recover efficiency is not the same as the conventional power efficiency, defined in terms of the power delivered to a load, since no power is delivered to the capacitor,  $C_p$ ; it is simply charged and then discharged. The recovery efficiency is a measure of the energy loss in the sustainer.

5 A circuit proposed for driving electroluminescent (EL) panels, published in M.L. Higgins, "A Low-power Drive Scheme for AC TFEI Displays", SID International Symposium Digest of Technical Papers, Vol. 16, pp. 226-228, 1985, was tested in the laboratory, but was abandoned since it was not capable of better than 80% energy recovery, and it has undesirable design complexities. A new very efficient sustain driver was then developed which eliminates the problems inherent in the prior proposed circuit.

10 First, a circuit model of the new sustain driver circuit will be analyzed to determine the expected recovery efficiency. The reasons why greater than 90% recover efficiency is possible with this new sustain driver will be explained, and several design guidelines will be given. Next, a constructed prototype of the new sustain driver will be discussed.

15 An ideal sustain driver circuit will be presented first to show the basic operation of the new sustain driver, given ideal components. As would be expected, given ideal components, this circuit has 100% recovery efficiency in charging and discharging a capacitative load. The schematic of the ideal sustain driver circuit is shown in Figure 5, and in Figure 6 are shown the output voltage and inductor current waveform expected for this circuit as the four switches are opened and closed through the four switching states. The operation during these four switching states is explained in detail below, where it is assumed that prior to State 1,  $V_{ss}$  is at  $V_{cc}/2$  (where  $V_{cc}$  is the sustain power supply voltage),  $V_p$  is at zero,  $S_1$  and  $S_3$  are open, and  $S_2$  and  $S_4$  are closed. The reason that  $V_{ss}$  is at  $V_{cc}/2$  will be explained, below, after the switching operation is explained:

20 State 1. To start,  $S_1$  closes,  $S_2$  opens, and  $S_4$  opens. With  $S_1$  closed,  $L$  and  $C_p$  form a series resonant circuit, which has a forcing voltage of  $V_{ss} = V_{cc}/2$ .  $V_p$  then rises to  $V_{cc}$ , at which point  $I_L$  is zero, and  $D_1$  becomes reverse biased. Alternatively, diode  $D_1$  could be eliminated and  $S_1$  opened when  $V_p$  rises to  $V_{cc}$  (at the point where  $I_L$  is zero).

25 State 2.  $S_3$  is closed to clamp  $V_p$  at  $V_{cc}$  and to provide a discharge current path for any "ON" pixels.

30 State 3.  $S_2$  closes,  $S_1$  opens, and  $S_3$  opens. With  $S_2$  closed,  $L$  and  $C_p$  again form a series resonant circuit, which has a forcing voltage of  $V_{ss} = V_{cc}/2$ .  $V_p$  then falls to ground, at which point  $I_L$  is zero, and  $D_2$  becomes reverse biased. Alternatively, diode  $D_2$  could be eliminated and  $S_2$  opened when  $V_p$  falls to zero (at the point where  $I_L$  is zero).

35 State 4.  $S_4$  is closed to clamp  $V_p$  at ground while an identical driver on the opposite side of the panel drives the opposite side to  $V_{cc}$  and a discharge current then flows in  $S_4$  if any pixels are "ON".

40 It was assumed above that  $V_{ss}$  remained stable at  $V_{cc}/2$  during the above charging and discharging of  $C_p$ . The reasons for this can be seen as follows. If  $V_{ss}$  were less than  $V_{cc}/2$ , then on the rise of  $V_p$ , when  $S_1$  is closed, the forcing voltage would be less than  $V_{cc}/2$ . Subsequently, on the fall of  $V_p$ , when  $S_2$  is closed, the forcing voltage would be greater than  $V_{cc}/2$ . Therefore, on average, current would flow into  $C_{ss}$ . Conversely, if  $V_{ss}$  were greater than  $V_{cc}/2$ , then on average, current would flow out of  $C_{ss}$ . Thus, the stable voltage at which the net current into  $C_{ss}$  is zero is  $V_{cc}/2$ . In fact, on power up, as  $V_{cc}$  rises, if the driver is continuously switched through the four states explained above, then  $V_{ss}$  will rise with  $V_{cc}$  at  $V_{cc}/2$ .

45 If this were not the case, a regulated power supply would be needed to supply the voltage  $V_{ss}$ . This would increase the overall cost of the sustain circuitry and could make this design less desirable.

50 The energy losses due to the capacitances and resistances inherent in the real devices, i.e., the switching devices, the diodes, and the inductor, can be determined by analysis of a practical circuit model shown in Figure 7. The switching devices are modeled by an ideal switch, an output capacitor, and a series "ON" resistor. The diodes (except  $D_{c1}$  and  $D_{c2}$ ) are modeled by an ideal diode, a parallel capacitor, and a series resistor, and the inductor is modeled by an ideal inductor and a series resistor.

55  $D_{c1}$  and  $D_{c2}$  are ideal diodes. They are included to prevent  $V_1$  from dropping below ground and  $V_2$  from rising above  $V_{cc}$ . As will be shown below, if  $D_{c1}$  and  $D_{c2}$  were not included, then the voltages across  $C_1$ ,  $C_{d2}$ ,  $C_2$ , and  $C_{d2}$  would be higher than otherwise, which would lead to additional energy losses.

60 The switching sequence of this circuit is the same as that of the ideal model shown in Figure 5. Figure 8 shows the voltage levels for  $V_p$ ,  $V_1$ ,  $V_L$ , and  $V_2$  and the current levels for  $I_L$ ,  $I_1$ , and  $I_2$  during the four switching states. Again, it is assumed that  $V_{ss}$  is stable at  $V_{cc}/2$ .

The recovery efficiency in the practical circuit model of Figure 7 can be determined below with reference to Figure 8. For example, the energy losses due to the capacitance of the switching devices (C1 and C2) and the diodes (Cd1 and Cd2) can be determined; then, the energy losses due to the resistances of the switching devices (R1 and R2), the diodes (Rd1 and Rd2), and the inductor (R<sub>L</sub>) can be determined; and finally, the energy loss due to the finite switching time of the switching devices can be determined. In each case, reference can be made to the four switching states, shown in Figure 8.

To find the power dissipation resulting from the capacitances of the switching devices and the diodes, an account is made of all the  $1/2CV^2$  loss. It is assumed that, initially, S1 and S3 are open, S2 and S4 are closed, V<sub>L</sub> is at ground, and V<sub>ss</sub> is at V<sub>cc</sub>/2.

10 State 1. To start, S1 closes and S4 opens. V1 and V<sub>L</sub> then rise to V<sub>ss</sub>, and the voltages across Cd2 (V<sub>2</sub>-V<sub>L</sub>) and across C1 (V<sub>ss</sub>-V1) both fall from V<sub>ss</sub> to zero. Thus, C1V<sub>ss</sub><sup>2</sup>/2 is dissipated in R1 and Cd2V<sub>ss</sub><sup>2</sup>/2 is dissipated in R1, Rd1, and R2. S2 then opens. With S1 closed, the series combination of R1, Rd1, L, and Cp is a series RLC circuit with a forcing voltage of V<sub>ss</sub> = V<sub>cc</sub>/2. The waveforms are shown in Figure 8. As I<sub>L</sub> falls to and crosses zero, then D1 becomes cut off and V<sub>L</sub> begins to rise.

15 State 2. S3 is closed to clamp V<sub>p</sub> at V<sub>cc</sub>. (Notice that before S3 closes, V<sub>p</sub> has not completely risen to V<sub>cc</sub>, due to the damping that was caused by R1, Rd1, and R<sub>L</sub>. Thus, when S3 is closed, V<sub>p</sub> is pulled p to V<sub>cc</sub> through S3, and a small amount of overshoot cold occur if there were stray inductances present in the real circuit. This overshoot is shown in the waveform for V<sub>p</sub> in Figure 8.) I<sub>L</sub> then becomes negative as C2 and Cd1 (V<sub>L</sub>-V1) both rise from zero to V<sub>ss</sub>, at which point Dc2 becomes forward biased and I<sub>2</sub> begins to flow. The energy in the inductor, when I<sub>2</sub> begins to flow, is then  $1/2(C2 + Cd1)Vss^2$ . This energy is dissipated in R<sub>L</sub>, Rd2, and R3 as I<sub>2</sub> falls to zero.

20 State 3. After the discharge current for any "ON" pixel cells has been supplied, then S2 closes and S3 opens. V2 and V<sub>L</sub> then fall to V<sub>ss</sub>, and the voltages across Cd1 (V<sub>L</sub>-V1) and across C2 (V<sub>2</sub>-V<sub>ss</sub>) both fall from V<sub>ss</sub> to zero. Thus, C2V<sub>ss</sub><sup>2</sup>/2 is dissipated in R2 and Cd1V<sub>ss</sub><sup>2</sup>/2 is dissipated in R2, Rd2, and R1. S1 then opens. With S2 closed, the series combination of R2, Rd2, R<sub>L</sub>, L, and Cp is a series RLC circuit with a forcing voltage of V<sub>ss</sub> = V<sub>cc</sub>/2. The waveforms are shown in Figure 8. As I<sub>L</sub> rises to and crosses zero, then D2 becomes cutoff and V<sub>L</sub> begins to fall.

25 State 4. S4 is closed to clamp V<sub>p</sub> at ground. (Notice that before S4 closes, V<sub>p</sub> has not completely fallen to ground, due to the damping that was caused by R2, Rd2, and R<sub>L</sub>. Thus, when S4 is closed, V<sub>p</sub> is pulled down to ground through S4, and a small amount of undershoot could occur if there were stray inductances present in the real circuit. This undershoot is shown in the waveform for V<sub>p</sub> in Figure 8.) I<sub>L</sub> then becomes positive as Cc1 and Cd2 are charged from the inductor. The voltages across C1 (V<sub>ss</sub>-V1) and across Cd2 (V<sub>2</sub>-V<sub>L</sub>) both rise from zero to V<sub>ss</sub>, at which point Dc1 becomes forward biased and I<sub>1</sub> begins to flow. The energy in the inductor when I<sub>1</sub> begins to flow is then  $1/2(C1 + Cd2)Vss^2$ . This energy is dissipated in R<sub>L</sub>, Rd1, and R4 as I<sub>1</sub> falls to zero.

30 Thus, it can be determined that the practical circuit model of Figure 7 results in a power loss of  $(f)E_{lost} = 0.17$  W, where the sustain frequency is equal to  $f = 50$  kHz. By comparison, if there were no energy recovery, then the normal loss from charging and discharging Cp would be  $(f)CpVcc^2 = 2.5$  W. The recovery efficiency (as previously defined) of the circuit of Figure 7 is

35 
$$Eff = 100 \times (1 - (E_{lost}/CpVcc^2)) = 93\%$$

40 where Cp = 5 nF and V<sub>cc</sub> = 100 V.

45 In summary, the practical circuit model of Figure 7 predicts the the new sustain driver will be capable of 93% recovery, assuming that the Q of the inductor is at least 80 and that the optimum tradeoff between switch output capacitance and "ON" resistance is realized.

The schematic of a constructed prototype sustain driver circuit is shown in Figure 9, and a complete parts list is given in Table 1.

50 It was found that the waveforms of the constructed circuit of Figure 9 correspond almost exactly with the waveforms of Figure 8 predicted from the circuit model of Figure 7.

55 Switches S1, S2, S3, and S4 in Figure 7 were previously described as being switched at the appropriate times to control the flow of current to and from Cp. In the prototype circuit of Figure 9, the power MOSFETs (T1, T2, T3, T4) replace the ideal switches of Figure 7 and must be switched at the appropriate times by real drivers to control the flow of current to and from Cp. Switching T1 and T2 at the appropriate times requires only that they are switched on the transition of V<sub>i</sub>. Thus, only a single driver (Driver 1) is required. Switching T3 and T4 presents a more difficult problem, however, since in addition to being switched on the transition of V<sub>i</sub>, they must also be switched whenever the inductor current crosses zero. This could have required that T3 and T4 be controlled with additional inputs to the Figure 9 circuit if it

were not the case that  $V_1$  and  $V_2$  make voltage transitions whenever  $V_i$  makes a transition and shortly after the inductor current crosses zero. Thus, the switching of T3 and T4 is accomplished by using the transitions of  $V_1$  and  $V_2$  to switch the Drivers (2 and 3) in Figure 9 at the appropriate times and no additional inputs are required.

5     Switching the MOSFETs can be seen with reference to Figure 9 and the following description. When  $V_i$  rises, the output of Driver 1 is switched "LOW" and the gates of T1 and T2 are driven "LOW" through the coupling capacitors,  $C_{g1}$  and  $C_{g2}$ . Thus, T1 is switched "ON", T2 is switched "OFF", and current begins to flow in the inductor to charge  $C_p$ . Also, D3 becomes forward biased and D4 is reverse biased. This causes Driver 2 to quickly switch "LOW", thus driving T4 "OFF", while Driver 3 is delayed from switching "LOW" 10 until after  $V_p$  has risen. (As will be explained later, R1 and R2 are needed only during initial startup when  $V_{cc}$  power is first applied and before  $V_{ss}$  has risen high enough for Drivers 2 and 3 to be switched from the changes in voltage of  $V_1$  and  $V_2$ .)

15     Referring back to the end of State 1 in Figure 8, it can be seen that  $V_2$ , in Figure 9 will begin to rise from  $V_{ss}$  to  $V_{cc}$  shortly after the inductor current into  $C_p$  has fallen to zero, at which time, T3 must be switched "ON" to clamp  $V_p$  at  $V_{cc}$ . In Figure 9, when  $V_2$  rises, then the input of Driver 3 also rises, due to the current through the coupling capacitor  $C_4$ . The output of Driver 3 then switches "LOW", and the gate of T3 is driven "LOW" throughout the coupling capacitor,  $C_{g3}$ . Thus, T3 is switched "ON" and clamps  $V_p$  to  $V_{cc}$ .

20     Later, when  $V_i$  falls, the output of Driver 1 is switched "HIGH" and the gates of T1 and T2 are driven "HIGH" through the capacitors,  $C_{g1}$  and  $C_{g2}$ . Thus, T1 is switched "OFF", T2 is switched "ON", and current begins to flow in the inductor to discharge  $C_p$ . Also, D4 becomes forward biased and D3 becomes reverse biased. This causes Driver 3 to quickly switch "HIGH", thus driving T3 "OFF", while Driver 2 is delayed from switching "HIGH" until after  $V_p$  has fallen.

25     When  $V_1$  begins to fall from  $V_{ss}$  to ground, shortly after the inductor current flowing out of  $C_p$  has fallen to zero (as at the end of State 1 in Figure 8), then the input of Driver 2 falls because of the coupling capacitor  $C_3$ . The output of Driver 2 then switches "HIGH", and the gate of T4 is driven "HIGH". Thus, T4 is switched "ON" and clamps  $V_p$  to ground.

30     Notice that an external timing circuit is not needed to determine when to switch T3 and T4 because the switching occurs shortly after the inductor current crosses zero, independent of the rise or fall time of  $V_p$ . This leads to simple circuitry that is independent of variations in the inductance ( $L$ ) or the panel capacitance ( $C_p$ ) and is a significant advantage over prior proposed sustain drivers. It also makes it possible to drive the circuit with only one input, so that if the input becomes stuck ("HIGH" or "LOW"), T3 and T4 cannot both be "ON" simultaneously, which would result in the destruction of one or both of the devices.

35     Another advantage that this circuit has over prior proposed circuits is that T1, D1, T2 and D2 need only be  $1/2 V_{cc}$  rather than the full  $V_{cc}$  voltage of prior circuits. Lower voltage switching devices, requiring lower breakdown voltages, are typically less costly to fabricate. This results in a lower parts cost for a discrete sustainer and lower integration costs for an integrated sustainer.

40     The resistors, R1 and R2 are provided for the case in which  $V_{ss}$  is at a very low voltage, such as during initial power up of  $V_{cc}$ . In this case, the voltages  $V_1$  and  $V_2$  do not change enough to cause the Drivers 2 and 3 to switch. The resistors will cause the Drivers 2 and 3 to switch, after a delay time, which is determined by the value of the resistors and the input capacitance of the Drivers.

45     The reason it is necessary to switch the Drivers 2 and 3 during initial power up when  $V_{ss}$  is very low, is as follows. In order for  $V_{ss}$  to rise, it is first necessary to T3 to switch "ON" and bring  $V_p$  up to  $V_{cc}$ . Then, when T2 turns "ON", a current will flow from  $C_p$  to  $C_{ss}$ . If T4 is later switched "ON", thus clamping  $V_p$  to ground, then when T1 turns "ON", the current that flows out of  $C_{ss}$  will prevent  $V_{ss}$  from rising above  $V_{cc}/2$ , and  $V_{ss}$  will begin to stabilize at  $V_{cc}/2$  after several cycles of charging and discharging  $C_p$ . Thus,  $V_{ss}$  will not achieve the proper voltage unless T3 and T4 are switched "ON" by the action of R1 and R2 during power up.

50     The resistor, R3, is provided to discharge the source to gate capacitance of T3 when the supply voltage,  $V_{cc}$ , suddenly rises during power up. Without R3, the source to gate voltage of T3 would rise above threshold, as  $V_{cc}$  rises, and remain there, with T3 "ON", after  $V_{cc}$  has risen. Then, if T4 were switched "ON", a substantial current would flow through T3 and T4 and possibly destroy one or both of the devices.

TABLE 1

## Part

|    | <u>Name</u> | <u>Number</u> | <u>Description</u>     | <u>Manufacturer</u> |
|----|-------------|---------------|------------------------|---------------------|
| 5  | T1          | IRF9530       | p-channel power MOSFET | Inter. React.       |
| 10 | T2          | IRF510        | n-channel power MOSFET | Inter. React.       |
|    | T3          | IRF9530       | p-channel power MOSFET | Inter. React.       |
|    | T4          | IRF510        | n-channel power MOSFET | Inter. React.       |
| 15 | D1          | 11DQ05        | power schottky diode   | Inter. React.       |
|    | D2          | 11DQ05        | power schottky diode   | Inter. React.       |
|    | D3          | IN3070        | high voltage diode     | Texas Instru.       |

## Part

|    | <u>Name</u>                           | <u>Number</u> | <u>Description</u>        | <u>Manufacturer</u> |
|----|---------------------------------------|---------------|---------------------------|---------------------|
| 20 | D4                                    | IN3070        | high voltage diode        | Texas Instru.       |
|    | Dc1                                   | IN3070        | high voltage diode        | Texas Instru.       |
|    | Dc2                                   | IN3070        | high voltage diode        | Texas Instru.       |
| 25 | INV                                   | MM74CO4       | CMOS inverter             | Nat. Semicon.       |
| 30 | Td1                                   | MPS6531       | NPN transistor            | Motor. Semicon.     |
|    | Td2                                   | MPS6534       | PNP transistor            | Motor. Semicon.     |
|    | L                                     | _____         | 2 $\mu$ H air coil        | J.W. Miller         |
| 35 | Cp                                    | _____         | 5 nF silver mica cap      | _____               |
|    | Css                                   | _____         | 1 $\mu$ F/ 50 volt cap    | _____               |
|    | C3                                    | _____         | 10 pF silver mica cap     | _____               |
| 40 | C4                                    | _____         | 10 pF silver mica cap     | _____               |
|    | Cg1                                   | _____         | .01 $\mu$ F/ 100 volt cap | _____               |
|    | Cg2                                   | _____         | .01 $\mu$ F/ 100 volt cap | _____               |
|    | Cg3                                   | _____         | .01 $\mu$ F/ 100 volt cap | _____               |
| 45 | R1                                    | _____         | 100K ohm 1/4 watt         | _____               |
|    | R2                                    | _____         | 100K ohm 1/4 watt         | _____               |
|    | R3                                    | _____         | 33K ohm 1/4 watt          | _____               |
| 50 | (All zener diodes shown are 12 volt). |               |                           |                     |

In an experimental setup for measuring the efficiency of the prototype circuit in Figure 9, the supply voltage ( $V_{cc}$ ) and the supply current were accurately measured while the circuit was driving a 5 nF capacitor load ( $C_p$ ). The load was driven at a frequency of  $f = 50$  kHz, with the supply voltage at 100 V. Thus, the normal power dissipation expected in this case was

$$\begin{aligned}
 P_{lost} &= (\text{energy lost to charge } C_p + \text{energy lost to discharge } C_p) \times f \\
 &= (1/2 C_p V_{cc}^2 + 1/2 C_p V_{cc}^2) \times f = 2.5 \text{ W.}
 \end{aligned}$$

5 The measured supply current for the Figure 9 circuit was 2.0 mA, so the actual power drawn from the supply and dissipated in the driver was 0.2 W. Thus, this circuit recovered all but 0.2 W of the normally lost power. The previously defined recovery efficiency is therefore 92%.

By comparison, the recovery efficiency predicted by analysis of the circuit model of Figure 7 is 93%. This is an indication that the most significant sources of power loss in the real circuit of Figure 9 have been 10 accurately accounted for in the model of Figure 7, and the model is a valid representation of the real circuit.

The sustain driver of Figure 9 can be used on each side of an ISA plasma panel. As an example, each of the sustain drivers XSA, XSB, YSA, YSB, in Figure 2 could be a sustain driver of Figure 9, and could be used with the open-drain address drivers previously described in connection with Figures 1-4.

After testing two sustain drivers (each as shown in Figure 9 with capacitor loads, one sustain driver was 15 connected to each side of a 512 $\times$ 512 ac plasma display panel. It was found that these sustain drivers could drive the panel with 90% recovery efficiency when no pixels were "ON", and that with all of the pixels "ON", the dissipation was still low enough that heat sinks were not necessary. With all of the pixels "ON", the power dissipation in T1 and T2 did not change, but the power dissipation in T3 and T4 increased due to the I<sup>2</sup>R losses resulting from the flow of discharge current. This power dissipation can be lowered by using 20 lower "ON" resistance devices for T3 and T4.

In testing the prototype sustain driver circuit of Figure 9, it was found that this circuit continued to charge and discharge the panel at the sustain frequency with high recovery efficiency, regardless of large variations in the panel capacitance or in the inductance of the coil. This is a distinct advantage over prior proposed sustain driver circuits.

25 It may be possible to substitute bipolar power transistors for the power MOSFETs, T1 and T2 in Figure 9 in a suitably designed circuit. Also, since the power dissipation and, hence, the cooling requirements have been significantly reduced in the sustain driver circuit of Figure 9, if all of the sustainer electrodes can be economically integrated onto a single silicon chip, then the complete sustainer can be packaged into a single case with one heat sink.

30 With reference to Figure 10, there is illustrated an integrated, power efficient sustain driver circuit according to the invention that does not require resistors or capacitors. In the circuit of Figure 10, T1 and T2 are driven directly by the Level Shifter, T3 is driven directly from the CMOS Driver Dr1, and T4 is driven directly from the CMOS driver Dr2. If C<sub>ss1</sub>, C<sub>ss2</sub> and the inductor are excluded from integration, then the integrated circuit is made up entirely of active components. Thus, the silicon area required is minimized.

35 The operation of this circuit is basically the same as the circuit of Figure 9. As before, T1 and T2 charge and discharge C<sub>p</sub> via L<sub>c</sub> and T3 and T4 clamp V<sub>p</sub> at V<sub>cc</sub> and ground, respectively. The difference is in the gate drive circuits Dr1, Dr2, and the Level Shifter, and in the addition of C<sub>ss1</sub>.

C<sub>ss1</sub> and C<sub>ss2</sub> form a voltage divider where C<sub>ss1</sub> = C<sub>ss2</sub>. Thus, at power up, when V<sub>cc</sub> begins to rise, V<sub>ss</sub> will rise at V<sub>cc</sub>/2. Later, when V<sub>ss</sub> has risen above the threshold level of the MOSFETs, then V<sub>ss</sub> will 40 be held at V<sub>cc</sub>/2.

45 The Level Shifter is a set-reset latch, with its output at either V<sub>cc</sub> or ground. When V<sub>i</sub> switches "HIGH", the output of the Level Shifter drops to ground and forces -V<sub>ss</sub> across the gate to source of both T1 and T2. This turns T1 "ON" and T2 "OFF". The input to Dr2 is then forced to V<sub>ss</sub>, the output of Dr2 drops to ground, and T4 is turned "OFF". Later, when I<sub>L</sub> falls to zero and then reverses, the input to Dr1 rises from V<sub>ss</sub> to V<sub>cc</sub>, the gate of T3 is then pulled down by Dr1 to V<sub>ss</sub>, and T3 turns "ON". Thus, V<sub>p</sub> is driven to V<sub>cc</sub> when V<sub>i</sub> switches "HIGH".

50 When V<sub>i</sub> switches "LOW", the output of the Level Shifter rises to V<sub>cc</sub> and forces V<sub>ss</sub> across the gate to source of both T1 and T2. This turns T1 "OFF" and T2 "ON". The input to Dr1 is then forced to V<sub>ss</sub>, the output of Dr1 rises to V<sub>cc</sub> and T3 is turned "OFF". Later when I<sub>L</sub> falls to zero and then reverses, the input to Dr2 falls from V<sub>ss</sub> to ground. The gate of T4 is then driven up by Dr2 to V<sub>ss</sub>, and T4 turns "ON".

55 The XAP and YAP address pulse generators may also be designed with the energy recovery technique previously described in connection with the sustain driver circuit. As an example, reference may be made to Figures 11-14. Figure 11 illustrates an XAP address pulse generator connected to the panel electrodes at the output terminal. Figure 12 illustrates the output voltage and inductor current waveforms (similar to Figures 5 and 6 with respect to the sustain driver) as switches S1 and S4 are opened and close, through the switching states. The output voltage waveform in Figure 12 is a positive double pulse conforming to the desired XAP waveforms of Figures 3 and 4. Notice that switch S2 of Figure 5 has been eliminated in the XAP generator of Figure 11 since diode D3 diode D2 and S. in Figures 5 and 6.

Figure 13 illustrates YAP generator and Figure 14 illustrates the corresponding waveforms in the switching states. Capacitor  $C_D$  and the output capacitance connected to the output terminal function as a voltage divider of voltage  $V_{CC}$  supplied to the circuit. When a Write Pulse is required. (See Figure 14), switch S5 is closed to short capacitor  $C_D$  to provide the full amplitude Write Pulse to the panel. If an Erase

5 Pulse is required, switch S5 is opened to provide the reduced amplitude Erase Pulse to the panel.

If desired, an ISA panel can be provided with N-channel MOSFET address drivers on one axis and P-channel MOSFET address drivers on the other axis, using techniques similar to the YAP and XAP address driver circuit techniques previously described. For example, a YAP address pulse generator with an N-channel MOSFET driver could be used with negative pulse similar to the negative pulses of the YAP pulses

10 in Figure 3. For the XAP address pulse generator a P-channel MOSFET driver could be used with a positive going single pulse having a pulse width equal to the width between the two double XAP pulses shown in the expanded view of Figure 4.

15 The foregoing detailed description has been given for clearness of understanding only, and no unnecessary limitations should be understood therefrom, as modifications will be obvious to those skilled in the art.

### Claims

20 1. A method for controlling (addressing and sustaining) cells and pixels of plasma panels, plasma display panels, electroluminescent panels, LCD's or that like having panel electrodes and corresponding panel capacitance in which the address cells and/or pixels are defined by the intersection of respective address electrodes in respective arrays of (X and Y dimension) address electrodes

25 characterized by the steps of:

bringing up the electrical potential of one address electrode (X) to a high level of one polarity; selecting whether to maintain (erase pixel) the high level of one polarity of said one address electrode (X) or to bring down (leave pixel on) the electrode to a low level of said one polarity in accordance with desired information to be entered into the cell or pixel of said panel/LCD; and

30 applying a high level of opposite polarity (YAP) to an respective other address electrode (Y) of the other dimension array after a high level of said one polarity has been selected at said other address electrode (Y), for pulling down the electrical potential of said other address electrode (Y) and for entering the desired information (erase/leave-on pixel) into the panel/LCD.

35 2. Method according to Claim 1,

characterized by bringing the electrical potential of said one address electrode (X) to a high level of said one polarity by applying a high level pulse (P1) of said one polarity to said one address electrode (X).

3. Method according to Claim 2,

characterized in that the high level pulse (P1) starts and terminates before the high level of opposite polarity is applied to said other address electrode (Y).

4. Method according to one of Claims 2 or 3,

characterized by applying a second pulse (P2) of said one polarity to said one address electrode (X) and bringing down the electrical potential of said one address electrode to said low level of said one polarity with the end of said second pulse (P2) for controllably discharging said one address electrode (X).

45 5. Method according to Claim 4,

characterized in that said second pulse (P2) starts and terminates after bringing back said other address electrode (Y) to said high level of said one polarity.

6. Method according to Claim 5,

characterized in that said high level pulses (P1, P2) and said high level of opposite polarity (YAP),

50 respectively, are (in general) applied simultaneously to all of the address electrodes of respective arrays of address electrodes (X, Y).

7. Method according to one of the preceding Claims characterized in that at least two different amplitude levels of said opposite polarity (YAP) are provided, one (higher) amplitude level (firing voltage) for writing information into the cell/pixel and the other (lower) amplitude level for erasing information from the cell/pixel.

8. Method according to one of the preceding Claims characterized in that the amplitude and shape of voltages applied to the respective arrays of address electrodes (X, Y) are defined by two generator means (XAP, YAP) and that said two generator means are connected to or separated from said address electrodes (X, Y) in accordance with the desired information to be entered into the cells or pixels.

9. Method according to one of the preceding Claims characterized by controlling Independent Sustain and Address (ISA) ac plasma panels having a plurality of X and Y dimension address electrodes, intersections between said address electrodes defining address cells,

10. a plurality of X and/or Y dimension sustain electrodes; each said X and/or Y address electrode positioned between and adjacent to two sustain electrodes of identical dimension (X or Y, respectively).

10. Method according to Claim 9 characterized by that the pixels corresponding to one address cell are (first) written simultaneously and (secondly) erased selectively in accordance with the information to be entered.

11. Method according to Claim 10 characterized in staggering of the write and erase operation of one address cell by at least one erase cycle of a further address cell.

12. A method for controlling (addressing and sustaining) cells and pixels of plasma panels, plasma display panels, electroluminescent panels, LCD's or that like having panel electrodes and corresponding panel capacitance in which the address cells and/or pixels are defined by the intersection of respective address electrodes in respective arrays of (X and Y dimension) address electrodes characterized by comprising the steps of:

charging the panel capacitance through an inductor, initially while storing energy in said inductor until the magnitude of the inductor current reaches a maximum, and secondly while removing the stored energy from said inductor until the inductor current reaches zero; and

discharging the panel capacitance through said inductor, initially while storing energy in said inductor until the magnitude of the inductor current reaches a maximum, and secondly while removing the stored energy from said inductor until the inductor current reaches after zero.

13. Method according to Claim 12 characterized by charging and/or discharging of the panel capacitance includes applying a forcing voltage which is about one-half the magnitude of the voltage level the panel capacitance reaches after charging.

14. Method according to one of Claims 12 or 13 characterized by including the steps of after charging/discharging the panel capacitance, maintaining the panel capacitance in a charged/discharged state prior to discharge/again charging the panel capacitance.

15. Method according to Claim 14 characterized by the step of maintaining the panel capacitance in a charged state includes clamping the voltage level of the panel capacitance upon the inductor current reaching zero, and wherein the step of maintaining the panel capacitance in a discharged state prior to again charging includes clamping the voltage level of the panel capacitance upon the inductor current reaching zero.

16. Circuit for controlling (addressing and sustaining) cells and pixels of plasma panels, plasma display panels, electroluminescent panels, LCD's or that like having panel electrodes and corresponding panel capacitance in which the address cells and/or pixels are defined by the intersection of respective address electrodes in respective arrays of (X and Y dimension) address electrodes characterized by

means for bringing up the electrical potential of an address electrode of one dimension array to a high level of one polarity;

means for selecting whether to maintain the high level of one polarity at said address electrode or to bring the electrode to a low level of said one polarity in accordance with desired information to be entered into the panel; and

means for applying a high level of opposite polarity to a respective address electrode of the other dimension array after a high level of one polarity has been selected at said address electrode of said one dimension array, for bringing down the electrical potential of the defined address cell and entering the desired information in the plasma panel.

17. Circuit according to Claim 16  
 characterized by that said means for bringing up and down the electrical potential of the address electrode of one dimension array includes means for applying a high level pulse of said one and of said opposite polarity, respectively, to said address electrode.

5 18. Circuit according to one of Claims 16 or 17  
 characterized in means for applying a (second) high level pulse of said one polarity to said address electrode of said one dimension array after entering said desired information or after the end of said high level pulse of opposite polarity for enabling the controllable bringing down of the electrical potential of said address electrode from said high level to said low level of said one polarity.

10 19. Circuit according to one of Claims 16 to 18  
 characterized in that said means for bringing up and/or down the potential of at least one of said address electrode (X, Y) comprise (pulse-) generator means (XAP, YAP) controllable connected with an output thereof via switching devices to each of said address electrodes.

20. Circuit according to Claim 19  
 15 characterized in that each of said switching devices is an identical semiconductor device, preferably a MOSFET device, most preferably an open-drain, n-channel device.

21. Circuit according to one of Claims 19 or 20  
 characterized in that one of said (pulse-) generator means (YAP) provides pulses of at least two different amplitude levels, one amplitude level for writing information into the panel and the other amplitude level for  
 20 erasing information from the panel.

22. Circuit for controlling (addressing and sustaining) cells and pixels of plasma panels, plasma display panels, electroluminescent panels, LCD's or that like having panel electrodes and corresponding panel capacitance in which the address cells and/or pixels are defined by the intersection of respective address electrodes in respective arrays of (X and Y dimension) address electrodes  
 25 characterized by an inductor (L) coupled to the panel electrodes, and a driver circuit coupled to the inductor (2) for operating the display panel through the inductor (2), the driver circuit including,  
 means for charging the panel capacitance through said inductor, initially while storing energy in said inductor until the magnitude of the inductor current reaches a maximum, and secondly while removing the  
 30 stored energy from said inductor until the inductor current reaches zero; and  
 means for discharging the panel capacitance through said inductor, initially while storing energy in said inductor until the magnitude of the inductor current reaches a maximum, and secondly while removing the stored energy from said inductor until the inductor current reaches zero.

35 23. Circuit according to Claim 22  
 characterized by comprising first means for clamping the voltage level of the panel capacitance upon the inductor current reaching zero during charging of the panel capacitance;  
 second means for clamping the voltage level to the panel capacitance upon the inductor current reaching  
 40 zero during discharge of the panel capacitance.

24. Circuit according to Claim 23  
 characterized by first and second means for clamping includes means responsive to the inductor current reaching zero to provide said clamping independent of variations in the values of said inductor or said panel capacitance.

45 25. Circuit according to one of Claims 22 to 24  
 characterized by first switch means coupled to said inductor to enable said panel capacitance to charge through said inductor from a first voltage level (a) initially to an intermediate voltage level magnitude which is about one-half the desired voltage level magnitude, while storing energy in said inductor, and (b) then to said desired voltage level magnitude, while removing said stored energy from said inductor; and second  
 50 switch means coupled to said inductor to enable said panel capacitance to discharge through said inductor from said desired voltage level magnitude (a) initially to an intermediate voltage level magnitude which is about one-half the desired voltage level magnitude, while storing energy in said inductor, and (b) then to said first voltage level magnitude, while removing said stored energy from said inductor.

26. Circuit according to one of Claims 22 to 25  
 55 characterized in that said means for charging/discharging the panel capacitance includes means for applying a forcing voltage which is about one-half the magnitude of the voltage level the panel capacitance reaches after charging.

27. Circuit according to one of Claims 22 to 26  
 characterized by including (switch) means for maintaining the panel capacitance in a charged state after charging the panel capacitance in prior to discharge, and/or (switch) means for maintaining the panel capacitance in a discharged state after discharge or upon the inductor current reaching zero and prior to again charging the panel capacitance.

5 28. Circuit according to Claim 27  
 characterized in that said means for maintaining the panel capacitance in a charged state includes means for charging the voltage level of the panel capacitance upon the inductor current reaching zero during charging of the panel capacitance, and wherein said means for maintaining the panel capacitance in a discharged state includes means for clamping the voltage level of the panel capacitance upon the inductor current reaching zero during discharging of the panel capacitance.

10 29. An ac plasma panel or a display panel comprising:  
 an array of X dimension electrodes;

15 15 an intersecting array of Y dimension electrodes with the intersections between respective X and Y electrodes defining a gas discharge cell or respective display pixels;

20 20 control means for applying a signal to selected X and Y electrodes to discharge at least one gas discharge cell or display pixel  
 characterized in that said control means comprise a circuit according to one or more of Claims 16 to 28.

25 30. An independent sustain and address ac plasma panel comprising:  
 a plurality of X and Y dimension address electrodes, intersections between said address electrodes defining address cells;

30 a plurality of Y dimension sustain electrodes; each said Y address electrode positioned between and adjacent to at least two sustain electrodes;

35 35 address means for applying an addressing signal during an addressing cycle to selected X and Y address electrodes to discharge at least one address cell, the plasma created by said discharge depositing residual wall charges at discharge sites associated with said two sustain electrodes in dependence upon the voltage existing at said discharge sites;

40 sustain means for subsequently energizing said sustain electrodes which energization in combination with said residual wall voltages selectively affects the discharge state of one or more said discharge sites;  
 characterized in that said address and/or sustain means comprise a circuit according to one or more of Claims 16 to 28.

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FIG.1

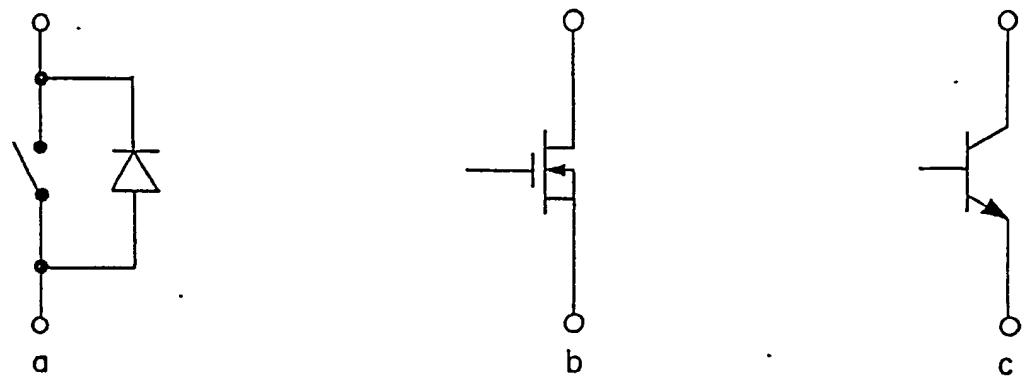


FIG.2

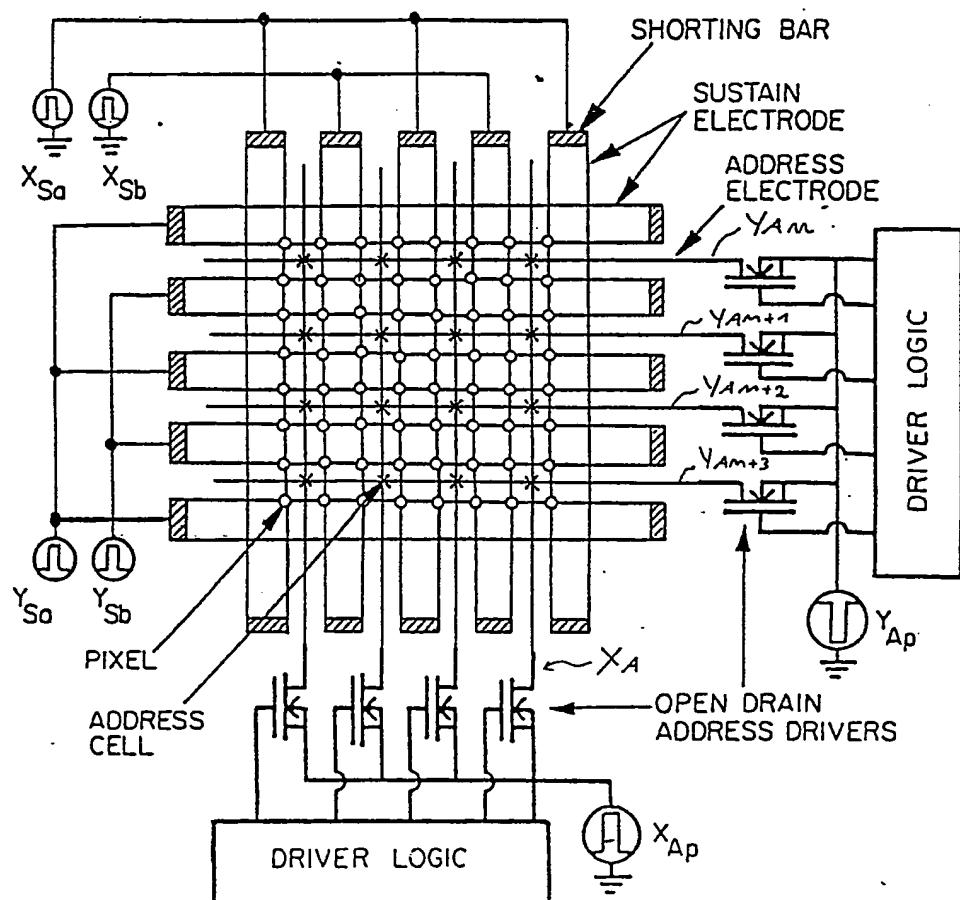


FIG. 3

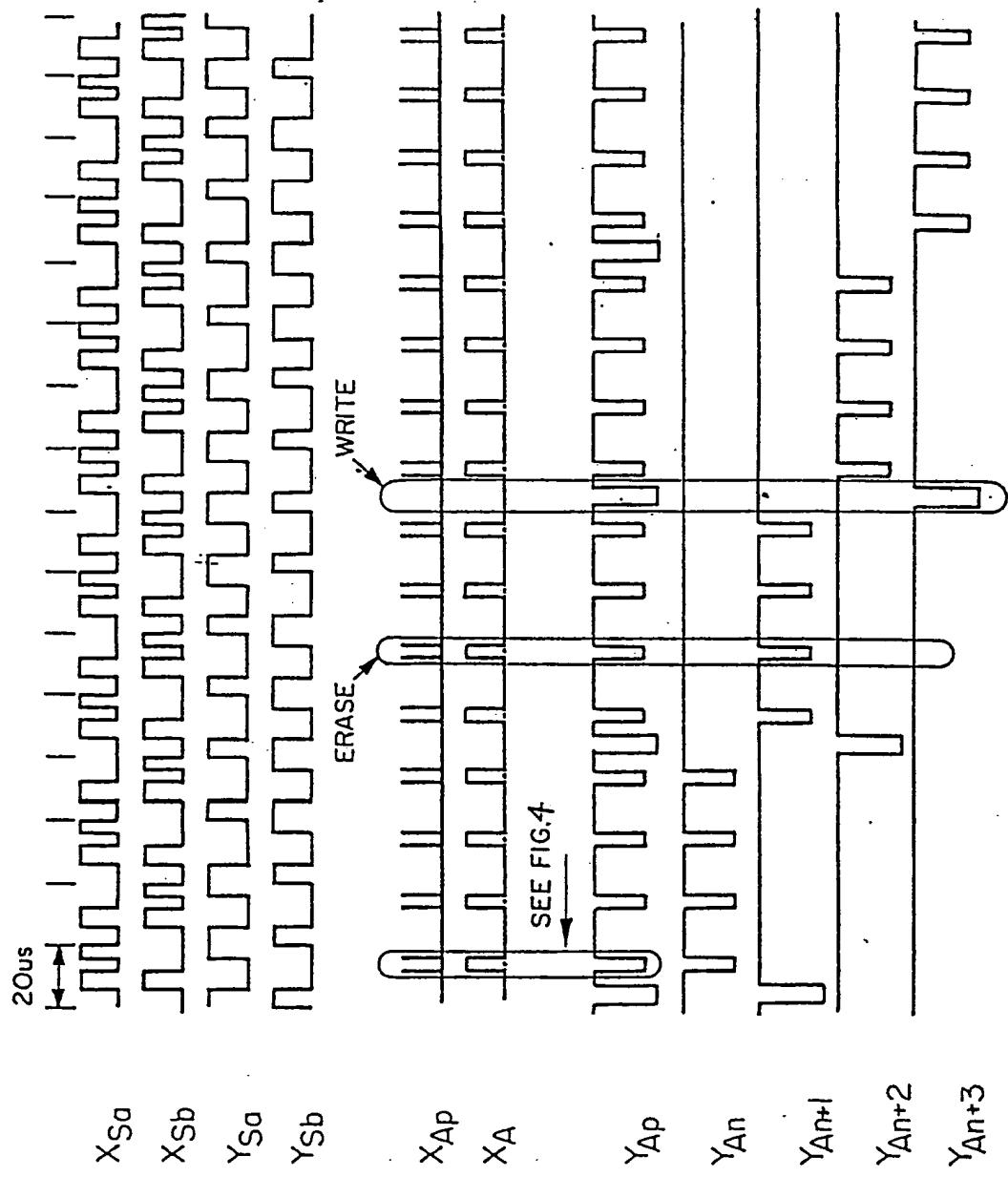


FIG.4

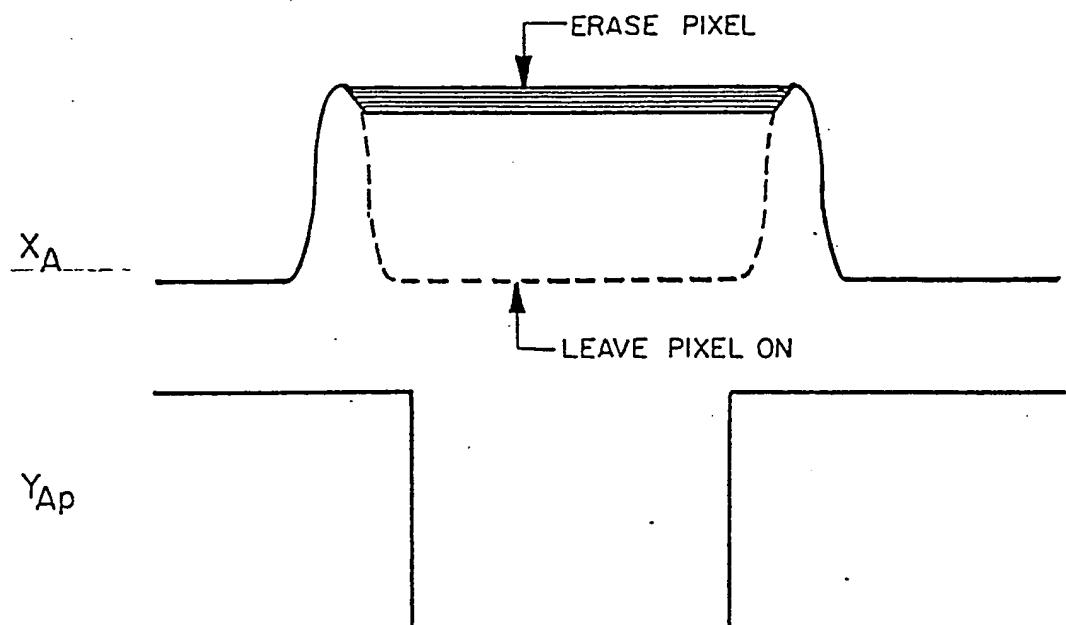
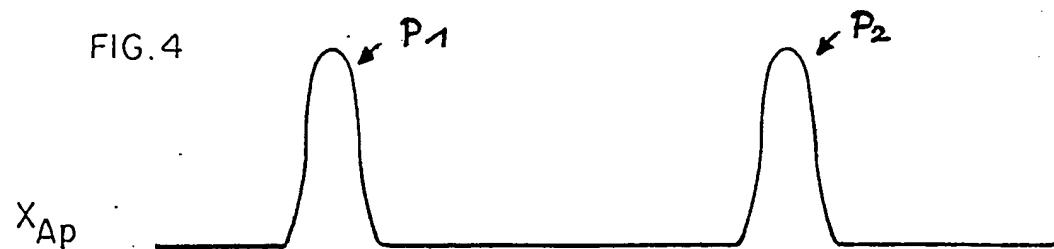


FIG.5

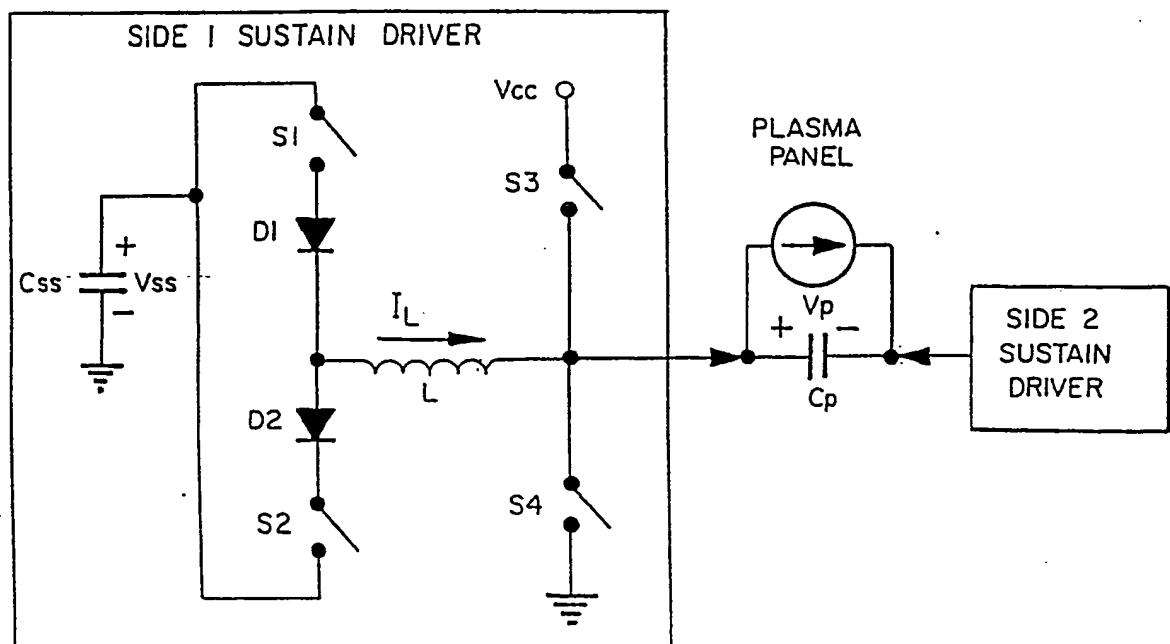


FIG. 6

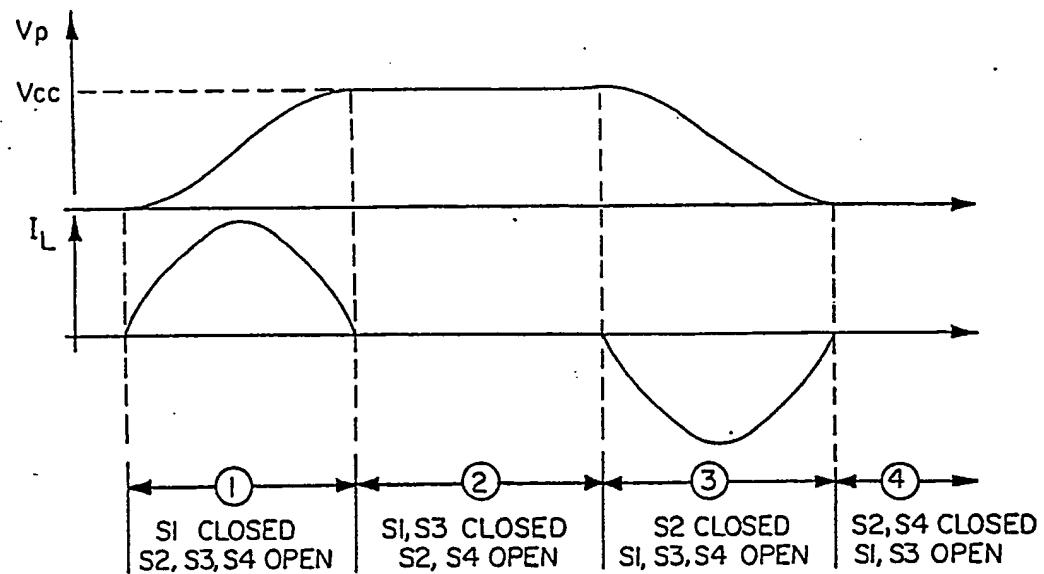


FIG. 7

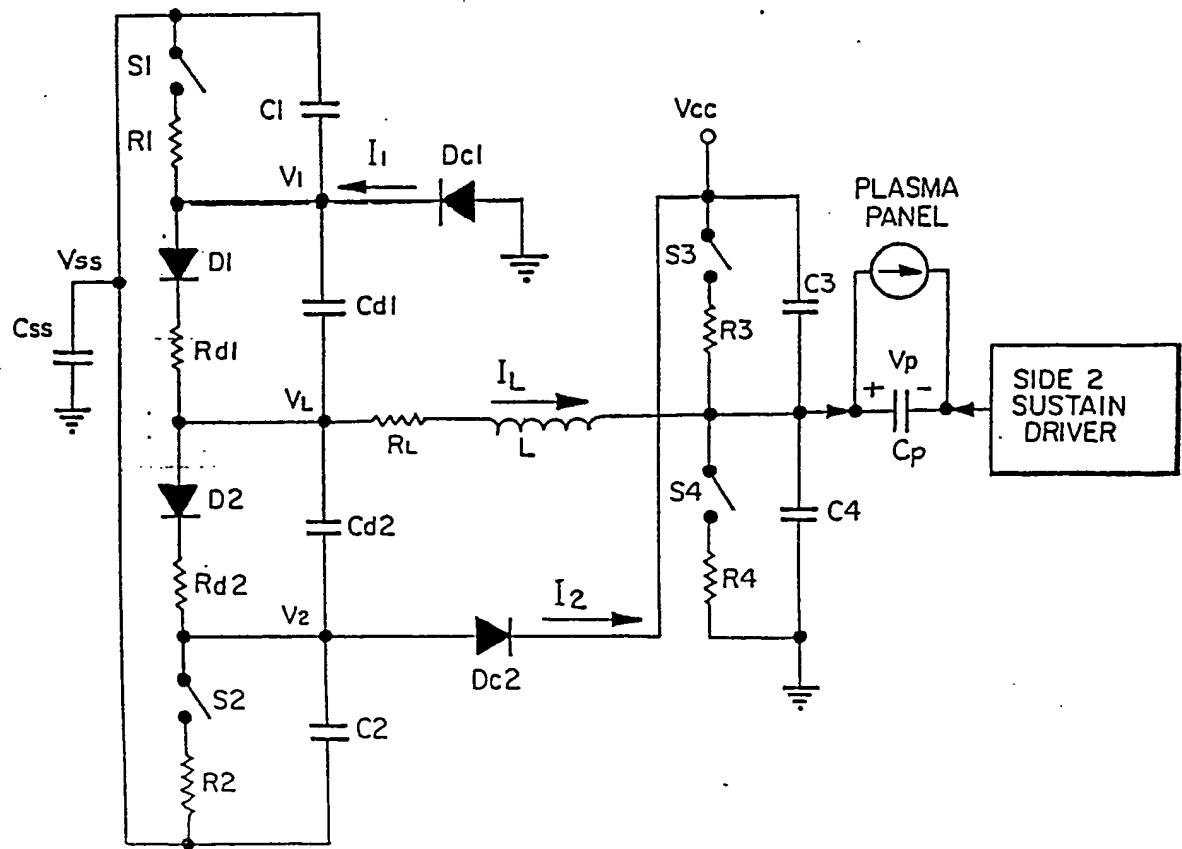


FIG.8

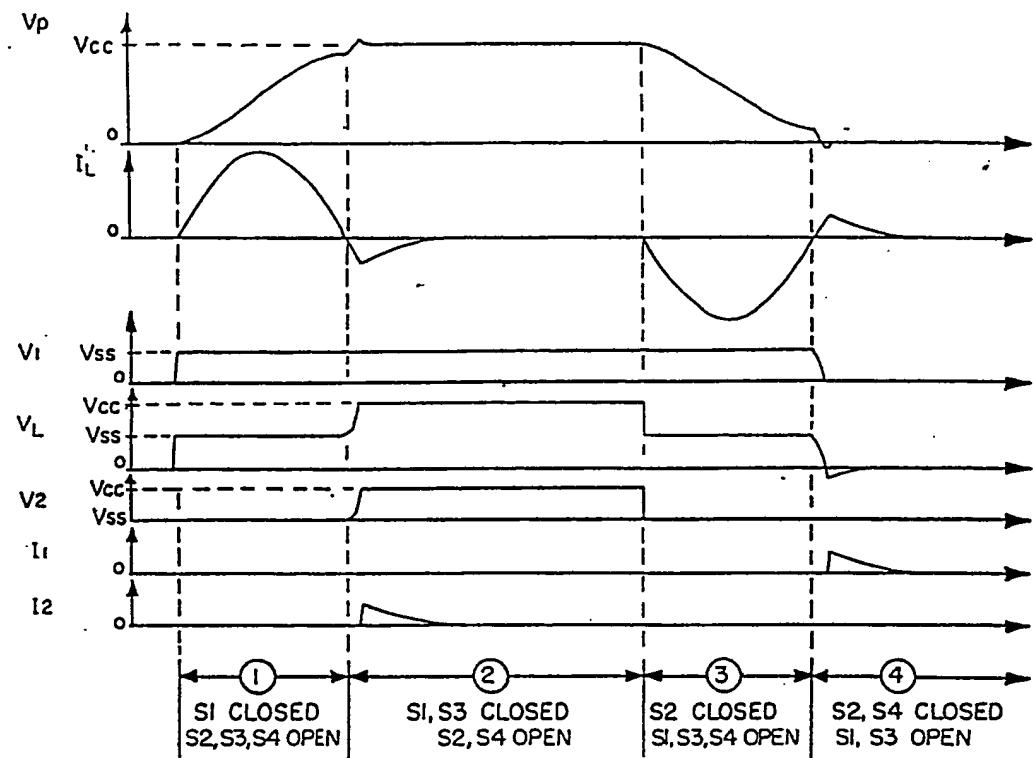


FIG.9

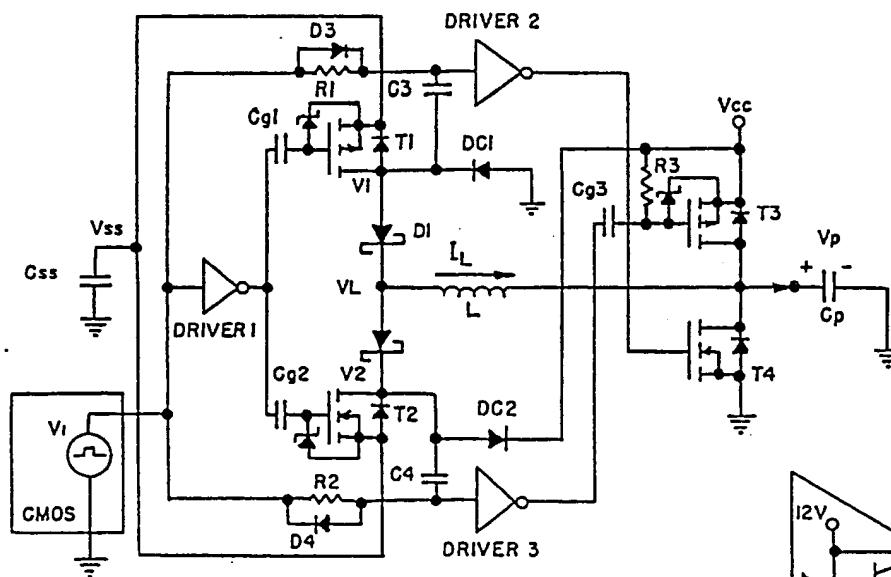


FIG.9a

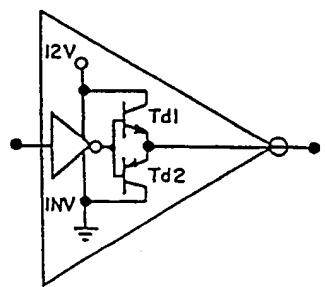


FIG. 10

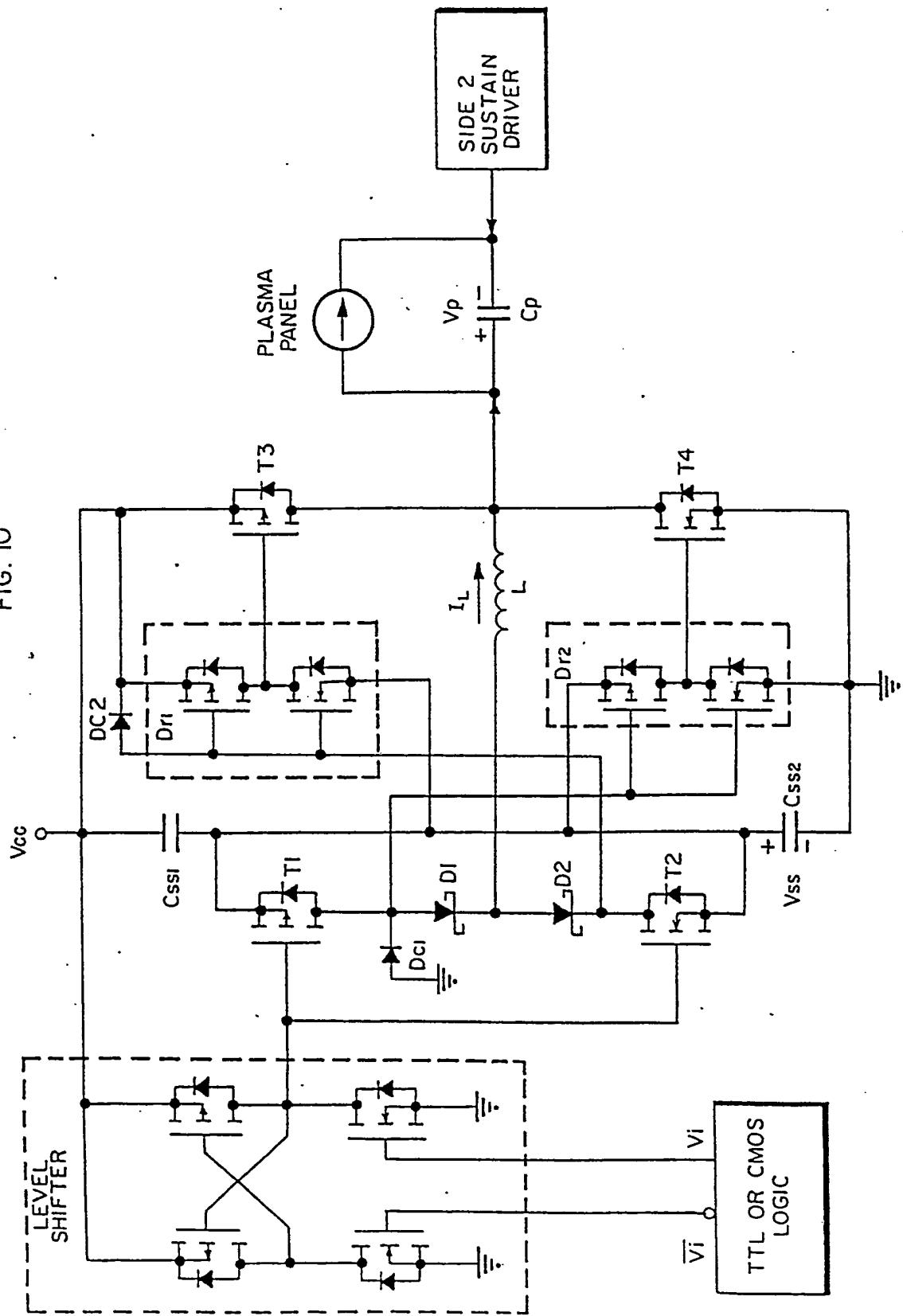


FIG.II

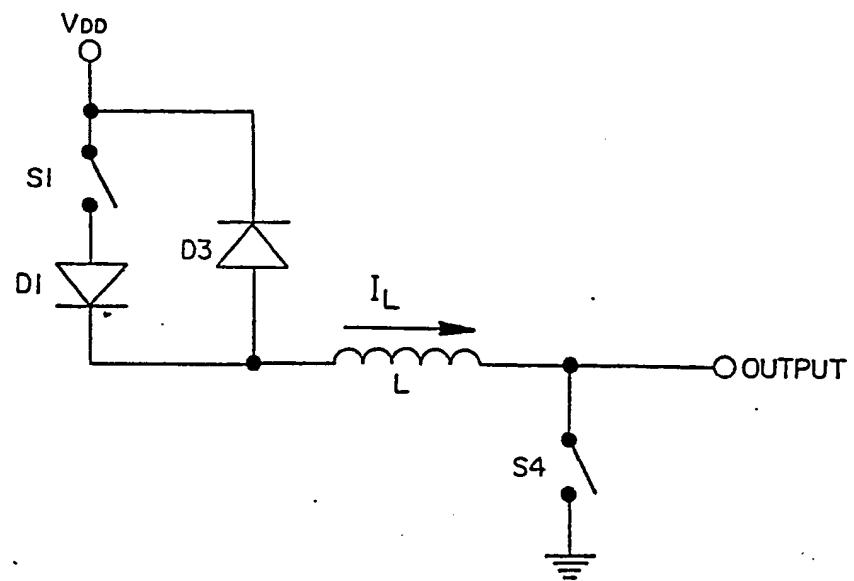
 $X_{AP}$ 

FIG.12

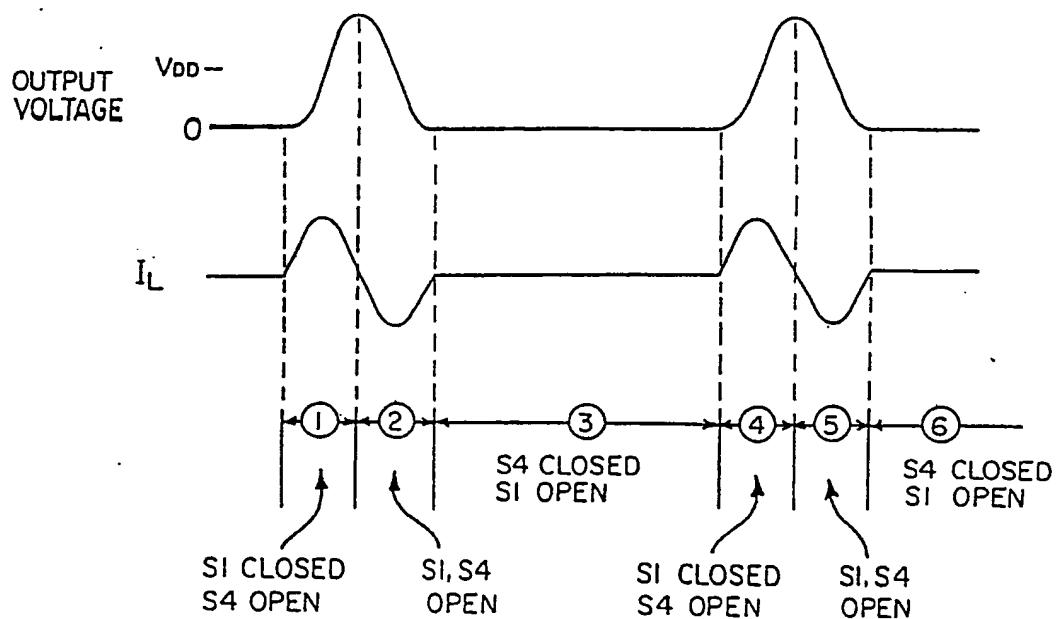


FIG. 13

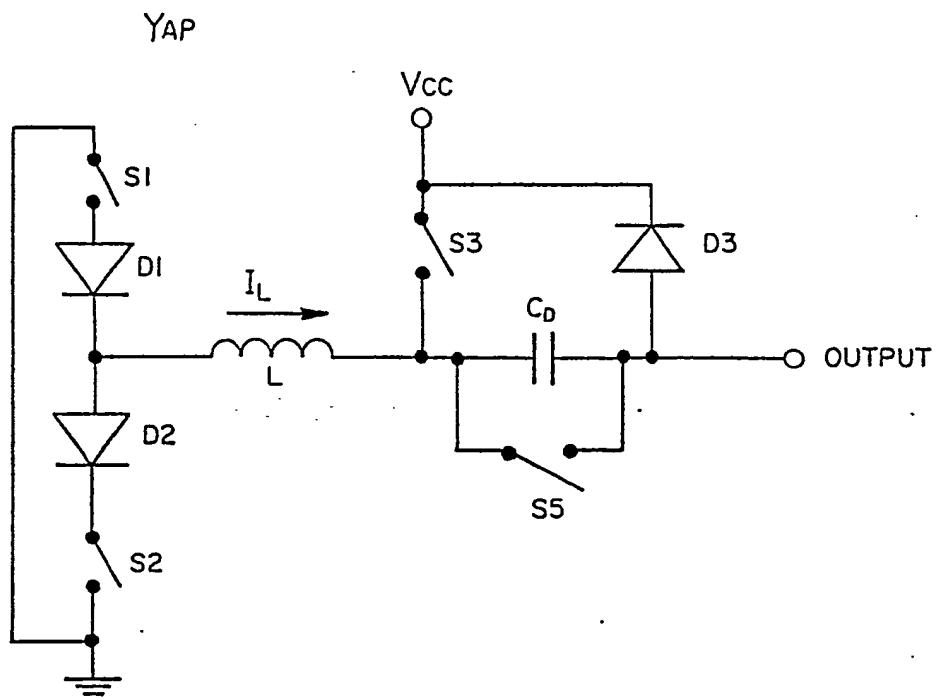
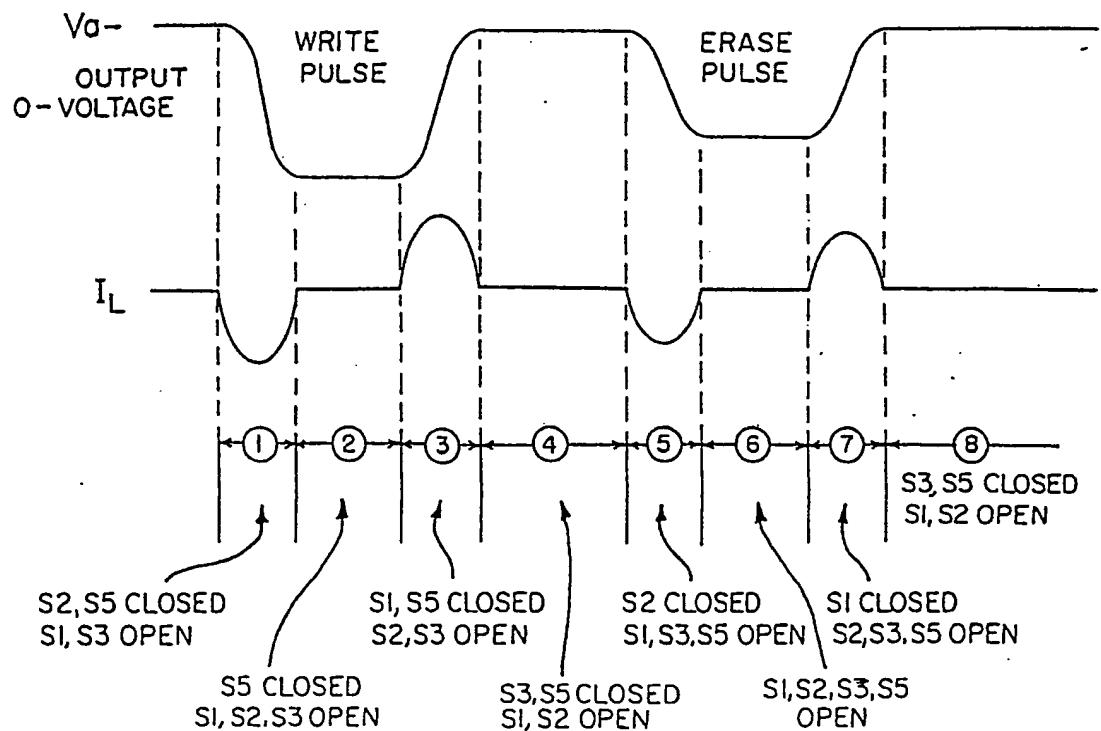


FIG. 14





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A3

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## EUROPEAN PATENT APPLICATION

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⑳ Applicant: The Board of Trustees of the  
University of Illinois  
266 Administration Building 506 South  
Wright Street  
Urbana Illinois 61801(US)

㉑ Inventor: Weber, Larry F.  
905 South Lynn  
Champaign, IL 61820(US)  
Inventor: Warren, Kevin W.  
723 South Lynn  
Champaign, IL 61820(US)  
Inventor: Wood, Mark B.  
680 West, 500 South  
Woods Cross Utah 84087(US)

㉒ Representative: Bohnenberger, Johannes, Dr.  
et al  
Meissner, Bolte & Partner  
Widenmayerstrasse 48 Postfach 86 06 24  
D-8000 München 86(DE)

㉓ Method for controlling cells and pixels of plasma panels, plasma display panels,  
electroluminescent panels, lcd's or that like and a circuit for carrying out the method.

㉔ An improved address driver circuit for plasma panels, particularly useful with an independent sustain and address plasma panel. Address pulse generators for one panel address axis are coupled to MOSFET driver devices and provide pulses of a first polarity; and address pulse generators for the other panel address axis are coupled to similar MOSFET driver devices and provide double pulses of a second polarity. With N-channel open-drain MOSFET drivers on both panel address axes, they only need to be designed to pull low. An improved power efficient sustain driver for plasma panels including an inductor through which the panel capacitance is charged and discharged, and switch means switched when the inductor current is zero, which permits recovery of the energy otherwise lost in driving the panel capacitance. An independent sustain and address plasma panel with such energy efficient ad-

dress drivers and sustain drivers. The energy efficient sustain driver can be used with plasma display panels, electroluminescent panels and with liquid crystal panels having inherent panel capacitance. An independent sustain and address panel with N-channel MOSFET drivers on one address axis and P-channel MOSFET drivers on the other address axis, with an address pulse generator providing pulses of a first polarity to the N-channel MOSFETs, and another address pulse generator providing pulses of a second polarity to the P-channel MOSFETs.

EP 0 261 584 A3



EP 87 11 3568

DOCUMENTS CONSIDERED TO BE RELEVANT

| Category  | Citation of document with indication, where appropriate, of relevant passages   | Relevant to claim  | CLASSIFICATION OF THE APPLICATION (Int. Cl.4) |
|---|---|--|---|
| X   | EP-A-0 044 182 (INTERSTATE ELECTRONICS CORPORATION)<br>* page 23, line 29 - page 27, line 5; figure 2 *   | 1-2, 7, 16-18, 29  | G 09 G 3/28                                   |
| Y   | ---   | 9  |   |
| D, Y  | SOCIETY FOR INFORMATION DISPLAY, INTERNATIONAL SYMPOSIUM CONFERENCE RECORD<br>1986, pages 220-223, May 1986, San Diego, US; L.F. WEBER et al.: "Independent Sustain and Address Technique for the ac Plasma Display Panel". * entire document * | 9  |   |
| X   | EP-A-0 071 260 (HITACHI LTD.)<br>* page 12, line 9 - page 13, line 19; figure 3 *   | 1, 2, 16-18  |   |
| D, A  | SID-SOCIETY FOR INFORMATION DISPLAY, INTERNATIONAL SYMPOSIUM DIGEST OF TECHNICAL PAPERS<br>vol. 16, 1985, pages 226-228, Los Angeles, US; M.L. HIGGINS : "A low-power drive scheme for AC TFEEL displays". * entire document *                  | 12, 22   | TECHNICAL FIELDS SEARCHED (Int. Cl.4)         |
| D, A  | US-A-3 559 190 (D.L. BITZER et al.)<br>* column 20, line 42 - column 21, line 17; figures 19 *  | 12, 22   | G 09 G<br>H 04 N                              |
| X   | EP-A-0 078 648 (SPERRY CORPORATION)<br>* page 12, line 28 - page 14, line 12; figure 8 *  | 1-2, 16  |   |
| The present search report has been drawn up for all claims  |   |  |   |
| Place of search   | Date of completion of the search  | Examiner   |   |
| BERLIN  | 12-05-1989  | KELPERIS K.  |   |
| CATEGORY OF CITED DOCUMENTS   |   | T : theory or principle underlying the invention<br>E : earlier patent document, but published on, or after the filing date<br>D : document cited in the application<br>I : document cited for other reasons<br>& : member of the same patent family, corresponding document |   |
| X : particularly relevant if taken alone<br>Y : particularly relevant if combined with another document of the same category<br>A : technological background<br>O : non-written disclosure<br>P : intermediate document |   |  |   |